

10-5 PROTECTION OF REINFORCEMENT AGAINST CORROSION DUE TO CHLORIDES, ACIDS AND SULFATES

General

Corrosion of steel reinforcement in concrete reduces the service life of a structure, as well as causes a reduction in its structural capacity. The factors that affect the rate of corrosion of reinforcement in concrete include the following:

- a) Presence of harmful chemicals (such as chlorides, acids, and sulfates), as well as the concentration of these chemicals.
- b) Availability of moisture and oxygen.
- c) Concrete density and permeability.
- d) Thickness of concrete cover.

While the rate of corrosion of reinforcing bars can be reduced by providing proper concrete cover, additional measures are needed to ensure adequate and efficient protection in harsh environments. Such measures include the use of corrosion resistant concrete (CRC) and the use of epoxy-coated reinforcement (ECR).

Article 8.22 in Caltrans' Bridge Design Specifications (BDS), together with Tables 8.22.1 and 8.22.2, give guidance to the Design Engineer in determining minimum required concrete cover and/or the use of ECR and CRC. Prior to using the tables, the Design Engineer should have the following information:

- i) Chloride content, acidity (pH value) and sulfate content of the surface water, ground water, and/or soil.
- ii) Mean lower low water (MLLW) level and mean higher high water (MHHW) level.

The above information is obtained from the foundation report and the log of test borings (LOTB) report. In addition, the distance from marine or brackish surface water to the bridge site shall be furnished to the Design Engineer.

The specifications in Article 8.22, and the Tables 8.22.1 and 8.22.2 in BDS, have been developed for a 75-year design life of a bridge structure. This design life span has been chosen to conform to the 75-year design life in AASHTO – LRFD specifications. However, it should be noted that the service life of a bridge deck is generally less than 75 years and is dependent on many factors such as load intensity, environmental effects, and maintenance. Therefore, the minimum cover requirements for the deck, as well as for the barrier rails, have been established considering that their service life may be less than 75 years.

The Design Engineer shall contact the Corrosion Technology Branch (CTB) in Materials Engineering and Testing Services to determine the minimum concrete cover if the specified design life of a structure exceeds 75 years or if the conditions encountered at the bridge site are not addressed in BDS Tables 8.22.1 and/or 8.22.2.

High Performance Concrete (HPC)

HPC is concrete that meets special requirements of performance and uniformity that cannot be achieved routinely using conventional constituents and normal practice. For example, HPC may be obtained by adding chemical admixtures, mineral admixtures, and/or by varying the water-to-cementitious material ratio. Generally, this type of concrete is developed with specific characteristics and for specific applications. Examples of specific requirements include reducing permeability, increasing density, increasing durability, improving ease in placement, and higher early strength (Concrete International, February 1999). FHWA has also proposed a more explicit definition for HPC based on performance criteria and testing requirements (Concrete International, February 1996).

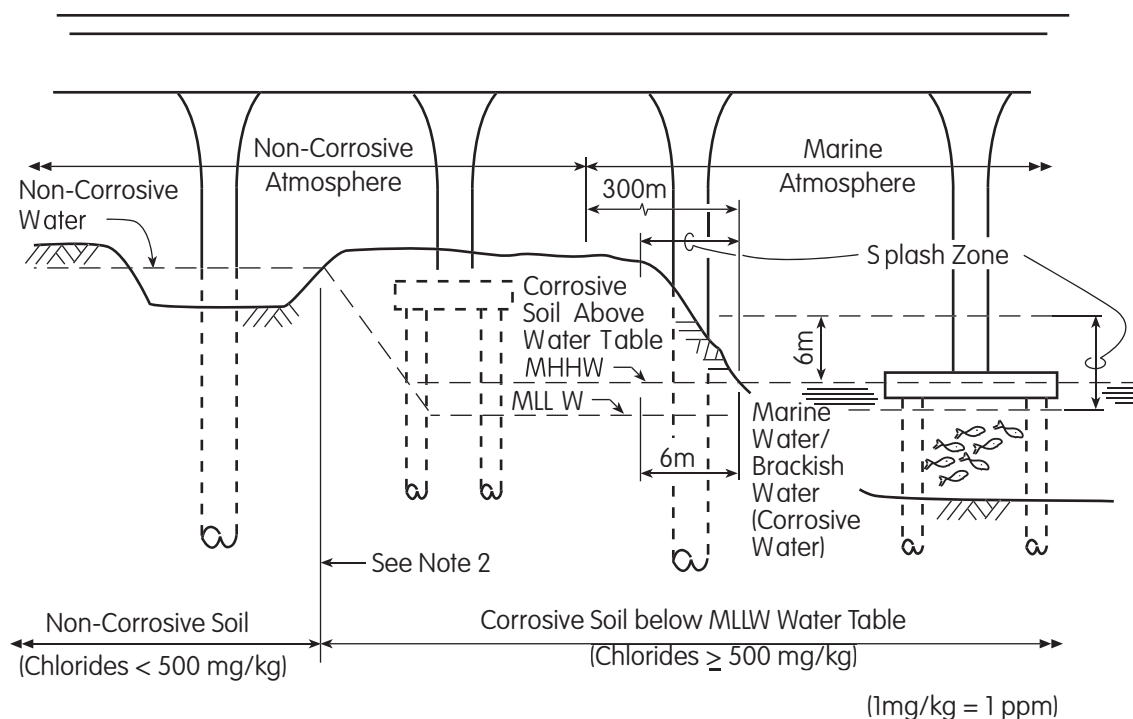
In Caltrans, CRC is a specific class of HPC, wherein concrete mix-design requirements are developed to minimize corrosion. The Design Engineer shall contact CTB and the Office of Rigid Pavement Materials and Structural Concrete (ORPMSC) to establish performance requirements and concrete mix-design requirements for a specific structure in a corrosive environment. This information shall be conveyed to the Specifications Engineer through a "*Memorandum to Specifications Engineer*."

Corrosion Protection from Chlorides

Corrosion Zones

Table 8.22.1 in BDS identifies the following exposure conditions: non-corrosive atmosphere, soil, and water; marine atmosphere; corrosive soil above and below the MLLW; corrosive water below the MLLW; corrosive splash zone (see MTD 10-6) and exposure to deicing salt, snow run-off, and snow blower spray (Climate Area III-*Memo to Designers* 8-2). In addition, Article 8.22.1 in BDS defines "Marine Atmosphere," "Tidal Water," and "Splash Zone." Corrosion of reinforcement in concrete may occur within any of these zones. In general, the rate of corrosion is highest within the splash zone where chlorides and oxygen are available in greater amounts. While corrosion of reinforcement in concrete which is immersed in tidal water is less severe than that in the splash zone, significant corrosion can still occur at large cracks in concrete when sufficient oxygen is available.

Figure 10-5(1) illustrates the different corrosion zones that are likely to be encountered in bridge design. Site specific information, when available, should be used to determine the range over which corrosive atmosphere adversely affects structures at a project site.



Notes:

1. The diagram shows limits of corrosive and non-corrosive conditions in the atmosphere, soil, and water. BDS Table 8.22.1 specifies actions required to protect reinforcement under these varying conditions.
2. The boundary between corrosive and non-corrosive soil conditions is to be determined by soil investigations at the site. Sulfate and pH assessments also may be required.
3. For additional information, refer to BDS 8.22.

Figure 10-5 (1): Corrosive Environment Diagram

Corrosion Control

BDS Article 8.22 and Table 8.22.1 provide a means to control rebar corrosion in concrete due to chlorides. Recent advances in concrete and corrosion technology, such as the use of ECR and CRC, have been utilized in developing these specifications as summarized below.

Epoxy Coated Reinforcement

The use of ECR slows the onset of corrosion and allows for reduced cover. Two types of ECR currently used in corrosive environments are the post-fabricated ECR (typically green in color) and the pre-fabricated ECR (purple or gray in color).

In post-fabricated ECR, the epoxy coating is flexible. Therefore, the rebar may be fabricated (bent to required shape) after the coating is applied. On the other hand, pre-fabricated ECR has a less flexible coating system, and the reinforcement is fabricated before the coating is applied. However, the coating used on pre-fabricated ECR provides a better adhesion and abrasion resistance as well as a more efficient protection against corrosion. Therefore, pre-fabricated ECR is generally specified for use in structural components that are within the salt-water splash zone and in barrier railing within 300 m from tidal water (see MTD 10-6).

Post-fabricated ECR shall be used in Climate Area III where required, and as specified in BDS Table 8.22.1. However, if design considerations (e.g., the need to reduce concrete cover) necessitate the use of pre-fabricated ECR in areas other than those specified in Table 8.22.1, then the Design Engineer shall obtain prior approval from the Deputy Chief, Division of Engineering Services, Structure Design.

Mineral Admixtures

BDS requires the use of mineral admixtures when concrete is exposed to corrosive conditions. The mineral admixtures conform to ASTM Designation C618 Type F or N (e.g., fly-ash), and/or ASTM Designation C1240 (e.g., silica fume). The latter mineral admixture is relatively more expensive, and may not be cost effective for all situations.

In general, the addition of mineral admixtures reduces the permeability of concrete to chloride ions. Mineral admixtures may slow the rate of strength gain in concrete, but do not adversely affect the long-term concrete strength.

BDS Table 8.22.1 specifies the quantity of mineral admixtures required to achieve the desired 75-year design life for different exposure conditions. Standard Special Provisions S8-C04(90CORR) also addresses the use of mineral admixtures in more detail, including proportioning requirements. Consult the ORPMS and CTB when using mineral admixtures in regions where freeze-thaw cycles are likely to occur.

Water-to-Cementitious Material Ratio

A low water-to-cementitious material ratio leads to a denser concrete. Table 8.22.1 identifies corrosion zones where this ratio shall not exceed 0.40.

Additional Corrosion Mitigation Techniques

In addition to the options discussed in the preceding paragraphs, protective measures such as the use of chemical admixtures, surface coatings, special curing techniques, protective overlays and cathodic protection, may be considered to improve the corrosion resistance properties of concrete and bridge components. Contact the ORPMSC and CTB to determine the suitability of such options.

Effects of CRC and ECR on Concrete Cover

In developing the minimum cover requirements in Table 8.22.1, the following guidelines have been used:

- a) Where post-fabricated ECR is specified, the minimum cover is reduced by 12.5 mm (from cover that is provided for uncoated reinforcement).
- b) Where pre-fabricated ECR is specified, the minimum cover is reduced by 25 mm (from cover that is provided for uncoated reinforcement).
- c) Concrete cover, where a combination of 5% mineral admixture conforming to ASTM Designation C1240 and 20% mineral admixture conforming to ASTM Designation C618 Type F or N is specified, is 25 mm smaller than the cover provided when concrete contains 25% by mass of mineral admixture conforming to ASTM Designation C618 Type F or N only.

In general, the Design Engineer shall ensure that the same combinations of CRC are used for any portion of a bridge that is constructed in the same concrete placement. For example, the same type of CRC should be specified for the stem and soffit of a box girder, while a different type of CRC may be specified for the deck. The Design Engineer should provide all necessary information on the corrosion protection measures that have been incorporated in his/her project to the Specifications Engineer through a "*Memorandum to Specifications Engineer*."

Concrete Piles in Corrosive Environments

In corrosive environments, piles shall be designed in accordance with BDS 8.22. Where the chloride concentration exceeds 10,000 ppm or when clear concrete cover exceeds 50 mm, standard pile details may not be adequate and site specific pile design may be required.

Corrosion Protection from Acids and Sulfates

Acids and sulfates have a detrimental effect on concrete and can adversely affect the performance and/or service life of a structure. Acidity of soil/water is determined by its pH value.

BDS Table 8.22.2 specifies the requirements for CRC when acids and/or sulfates are encountered. It is noted that the difference in compressive strength between concrete obtained with Type II modified cement and Type V cement is not significant.

Table 8.22.2 lists soil/water pH and sulfate concentration in increasing levels of severity with reference to corrosion. For example, a pH of '3 to 5.5' is more corrosive than a pH of '7.1 to 14'; a sulfate content of '2000 ppm to 15000 ppm' is more detrimental than that of '0 ppm to 1499 ppm'. If, at a bridge site, the soil/water pH and sulfate concentrations are at different levels of severity, then the more corrosive condition shall govern. For example, in a situation where the soil has a pH of 4.0 and a sulfate concentration of 1500 ppm, the CRC requirements for soil with a pH of 4.0 shall govern.

When the pH of soil/water at the bridge location is less than 3.0 or when the sulfate content exceeds 15,000 ppm, contact the Corrosion Technology Branch and the Concrete and Structures Testing Branch.

References: BDS 8.22, MTD 3-1, MTD 8-2 and MTD 10-6.

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